

AN INVESTIGATION OF STRESS  
CONCENTRATION FACTORS AROUND  
SELECTED OPENINGS USING THE BRITTLE  
LACQUER TECHNIQUE

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Annapolis, Md.





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AN INVESTIGATION OF STRESS CONCENTRATION  
FACTORS AROUND SELECTED OPENINGS USING  
THE BRITTLE LACQUER TECHNIQUE

Submitted to the Faculty of  
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by

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and

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Thane  
1885

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Submitted to the Board of  
Naval Engineers for their  
in final approval of the  
specifications for the design of  
the ship of the line.

by

John L. Parsons

and

Alfred H. Brown

NEW YORK  
JANUARY, 1885

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The investigators also wish to express their appreciation to all persons of the Bureau of Yards and Docks who cooperated so completely in furnishing the necessary details to initiate this project.



ABSTRACT

The objectives of this study were twofold. The first was an investigation of the use of the relatively new technique of brittle lacquer for determining quantitatively certain stress concentration factors. The succeeding objective, depending on satisfactory results of the first, was the actual determination of the factors for certain selected openings of particular shapes and sizes.

The authors have attempted to point out the practical problems and considerations involved in the use of brittle lacquer for a study of this kind. It was found that the technique is quite practicable, especially for odd shaped pieces or openings and that for large scale operations the investment in the brittle lacquer equipment and its use would be advisable.

The factors obtained for the particular openings used in this project are found in the data section of this report.





## INTRODUCTION

The object of this investigation was to determine if brittle lacquer could be successfully used to investigate stress concentration factors around circular, semi-elliptical, and bi-elliptical openings in flat plates subject to uni-axial loading; and, if so, to determine the stress concentration factors around these selected openings.

The term stress concentration factor as used in this paper is defined as the ratio of the maximum stress to the average stress in the minimum section. The term bi-elliptical opening is used in referring to openings consisting of halves of two ellipses having a common major intercept but different minor intercepts.

The importance of stress concentration factors around commonly used openings is obvious and has been the subject of considerable research and study. The particular openings chosen for this investigation were suggested by the Bureau of Yards and Docks of the U. S. Navy. They consisted of openings which are commonly used in drydock and tunnel construction and about which there is very limited data available. The tunnel pillar problem constituted one set of openings investigated. This consisted of semi-elliptical openings with bases along a common line separated by pillars of varying depth. The importance of this problem is obvious in tunnel

# INTRODUCTION

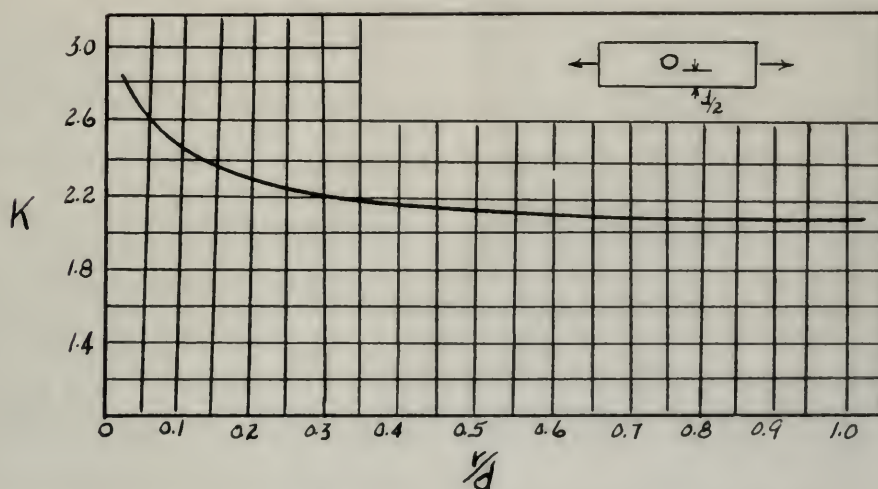
The object of this investigation was to determine if  
 certain factors would be statistically used in investigations  
 where conventional factors are used. The factors used were  
 and statistical analysis in that they were used in the  
 and analysis; and, if so, to determine the factors con-  
 sidered in the analysis of these factors.

The first factor considered in this  
 paper is defined as the ratio of the number of cases to the  
 average number in the analysis. The ratio of 1.0 is  
 considered as used in the analysis of the factors of  
 cases of two different types of cases. The ratio of 1.0 is  
 considered as used in the analysis of the factors of

The importance of these factors in the analysis of  
 commonly used factors is obvious and has been the subject of  
 statistical analysis and study. The results of the  
 studies for this investigation were suggested by the factors  
 of cases and those of the V. A. Navy. They consisted of com-  
 ing cases and commonly used in the analysis and common factors  
 and those cases which are very limited data available.  
 The common cases considered are not of the same  
 investigated. This consisted of statistical analysis  
 with cases and a common line reported by others of very  
 the cases. The importance of this problem is obvious in the

work and other construction where openings of this type are frequently used.

The problem of stress concentrations around simple openings, such as a small circular opening in a plate of infinite width, is one which has been thoroughly analyzed and studied. The theoretical analysis of this problem gives a stress concentration factor of three where the width is great compared to the diameter of the hole. The variation of the factor with the ratio of radius of hole to width of plate is reproduced below from "Strength of Materials"--Part II by S. Timoshenko. It can be seen that the factor



decreases considerably as the ratio  $r/d$  increases.

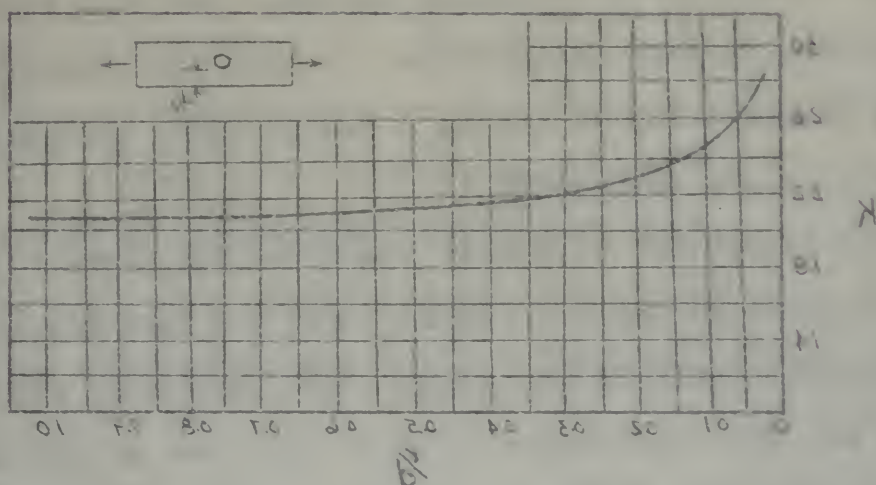
For elliptical holes the following is quoted from the above reference: "In the case of a small elliptical hole in a plate the maximum stress is at the ends of the horizontal axis of the hole, and is given by the equation:

$$f_{\max.} = f(1 + 2a/b)$$



with and other communication means consisting of this type are  
 frequently used.

The problem of these communications around electric  
 circuits, which as a small circuit working in a state of  
 infinite time, is one which has been thoroughly analyzed  
 and studied. The theoretical analysis of this problem  
 gives a series of communication factors of which some are shown  
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 of factor is represented below the "factor of factor" --  
 and it is given by the factor. It is given by the factor



decrease considerably as the factor increases.  
 The typical factor and following is noted from the  
 factor diagram. In the case of a small circuit there  
 is a point the maximum factor is at the end of the factor  
 and it is given by the factor.

$$E_{max} = 1/1 + 1/2$$

where  $f$  is the tensile stress applied at the ends of the plate. This stress increases with the ratio  $a/b$ , so that a very narrow hole perpendicular to the direction of tension produces a very high stress concentration." The above reference gives no indication that the stress concentration factor might vary with the ratio of the width of opening to the width of the plate. This is a summary of the meager information available on the problem.

The problem was not only the one of determining the stress concentration factors for the three types of openings suggested, but also of determining the variation of the factor for multiple openings of each type with varying depths of pillars between. A theoretical analysis would not only be extremely complex, but would be of doubtful practical value. From the practical stand-point there were two methods available for investigation of the problem: photoelasticity and brittle lacquer. Strain gages would only give an average value of strain over the gage length. This could cause an appreciable and indeterminate error even over a 1/8 inch gage length. Several factors favored the use of brittle lacquer. Many tests could be run in the limited time available. The technique is fairly new and does not require extensive preparation. It was felt that the results could be checked by the photoelastic method if time permitted.

The Navy Department wished to obtain the stress concentration factors for plates subject to a uniform compressive

[illegible]

The system was not only the most of maintaining the  
these communication is also for the three types of signals  
collected, but also of maintaining the relation to the  
factor the subject's response of each type with varying degrees  
of clarity between. A theoretical weight is given to each  
on extremely complex, but would be of considerable importance  
value. From the physical point of view, there was no reason  
available for investigation of the problem, particularly  
was not in order. While these results were given as a rough  
value of error over the page length. This could be used as  
theoretical and experimental error over a 1/8 inch page  
length. Several factors entered the use of metric system.  
They could be used in the United States. The  
technology is highly new and some are already in use  
operation. It was not only the results could be used by  
the scientific method is also possible.

The Navy Department advised in 1941 that the United States Navy was not planning to build a fleet of aircraft carriers.



load. There were many difficulties, however, which would be encountered in the use of brittle lacquer in testing compression loads. The plates would have to be coated under load, then allowed to dry and the load released. Such a procedure would be extremely cumbersome with the equipment available. Since the load would be uni-axial in any case, the investigation was conducted with tension loads. The factors will, of course, be identical for both tension and compression loads.

During the course of the experiment the investigation was carried out in three principal parts. The first part consisted of tests using moderate oven temperatures for drying; the second part, drying in air; the third part, using higher temperatures in conjunction with another research project.



### PREPARATION OF MATERIALS

After having determined the number and type of openings to be tested, the investigators were faced with the problem of determining the material and dimensions of the specimens and the design and construction of the necessary apparatus for testing the specimens. The material to be used for the specimens should have two properties: it should have a low modulus of elasticity, to yield a maximum strain with the least stress, thus reducing the load required to fracture the lacquer; and it must have a sufficiently high yield point to sustain strains of at least five times that required to fracture the lacquer without yielding. This is necessary in order to examine the strains over the entire plate without causing local yielding around the openings. The material which best fulfilled these qualifications was 24 ST aluminum, which has a modulus of 10,300,000 psi and a tensile strength of 44,000 psi.

The thickness of the plate should be the smallest which would allow handling and working without warping. The investigators decided to use 1/8" plate for the tests. However, since this was not available, 3/16" plate was substituted.





The relative dimensions of the plates and openings as prescribed by the Bureau of Yards and Docks are as follows:

Circular openings-- $r/h = 1/15$  or  $1/20$  where  $r$  is radius of opening and  $h$  is depth of plate.

Half-elliptical openings-- $a/h = c/2h = 1/15$  or  $1/20$  where  $a$  is minor intercept and  $c$  is major intercept.

Bi-elliptical openings--same as semi-elliptical openings but with bottom minor intercept of  $a/3$ .

The selection of the proper scale was very important for the proper interpretation of results. In determining the actual dimensions of the openings, the investigators felt that the minimum depth of opening should be  $3/4"$  to facilitate fabrication of the samples and examination of the lacquer during testing. This depth of opening would require a clear depth of plate between  $11.25"$  and  $15"$ . The maximum width of any opening would then be  $3"$ . In order to test two or more openings with varying depths between, the width of the plate must be about  $16"$  to  $18"$ . Actually  $3/4"$  was used for the  $a$  and  $r$  dimensions indicated above. The clear depth of plate was about  $13"$  and the width about  $16"$  or  $18"$ .

The fabrication of the circular holes presented no difficulties. The holes were drilled and reamed to size. The edges of the holes were polished to remove the rim left by the reaming operation, then checked to make sure the edges of the holes were perpendicular to the faces of the plates. Care was taken to insure that all holes had sharp, square

The relative dimensions of the plates and openings as  
 specified by the Bureau of Roads and Bridges are as follows:  
 distance openings- $2\frac{1}{2}$  in. =  $1\frac{1}{2}$  in. or less; and the distance  
 of opening and  $g$  is equal to plate.

Half-spherical openings- $2\frac{1}{2}$  in. =  $1\frac{1}{2}$  in. or less  
 $g$  is about thickness and  $g$  is about interval.

Elliptical openings- $2\frac{1}{2}$  in. or less-elliptical openings  
 are with plates about thickness of  $2\frac{1}{2}$  in.

The selection of the proper plate and opening for  
 the proper investigation of results. In determining the

actual dimensions of the openings, the investigators have found  
 the minimum depth of opening should be  $2\frac{1}{2}$  in. or less.

Location of the openings and openings of the openings  
 during testing. This depth of opening should require a clear

depth of plate between  $11\frac{1}{2}$  in. and  $15\frac{1}{2}$  in. The minimum depth of  
 the opening should be  $2\frac{1}{2}$  in. In order to have the same

openings with varying depths between the ends of the plate  
 must be about  $15\frac{1}{2}$  in. to  $19\frac{1}{2}$  in. Actually  $2\frac{1}{2}$  in. was used for the  $g$

and a specimen indicated above. The clear depth of plate  
 was about  $15\frac{1}{2}$  in. and the clear depth  $20\frac{1}{2}$  in.

The location of the openings was determined by  
 dimensions. The holes were drilled and reamed to size.

The edges of the plates were polished to remove the burrs  
 of the opening operation; then tested to see how the edges

of the plates were polished; to the ends of the plates.  
 Care was taken to insure that all holes and edges, etc.

edges without any overhang or rounding.

The semi-elliptical and bi-elliptical holes presented a considerable fabrication problem. There was neither time nor facilities available to obtain dies to punch the openings. The only solution seemed to be to drill and file the openings to proper size. The pattern was made by scribing a perfect ellipse on a plate using two pins and a taut cord. This plate was then used as a pattern for the other openings to insure uniformity. While this was a very tedious procedure, the openings were very carefully made to the precision desired. The edges were carefully filed to right angles and the corners were filed to the exact contour desired. All corners and edges were then polished smooth with emery cloth. It was felt that this was largely responsible for the uniformity of the results obtained.

The openings tested are illustrated on Figure I. Besides the tests of single openings of the relative dimensions illustrated, tests were made using plates with the following combinations of openings:

1. three circular openings 3" o.c.
2. two semi-elliptical openings 5", 6" and 7" o.c.
3. two bi-elliptical openings 5", 6" and 7" o.c.

It was hoped that the experiments would illustrate any variation in stress concentration factor with variation in pillar depth.



about without any covering or insulation.

The semi-cylindrical and cylindrical tubes measured

approximately 100 centimeters in length. There was a certain time

and therefore it was possible to observe the effect of the opening.

The only condition seemed to be the width and the length

of the tubes. The tubes were made of varying

widths of a half inch, one inch, and a half inch.

This table was made as a reference for the other openings

to insure uniformity. While this was a very simple

method, the openings were very carefully made to the condition

desired. The tubes were carefully tested to insure uniformity

and uniformity was found in the most accurate manner. All

curves and edges were then polished smooth with emery cloth.

It was found that this was entirely satisfactory for the

uniformity of the results obtained.

The openings tested are illustrated in Figure 1. Section

and cross-sections of the openings at the various diameters

illustrated, and the results obtained with the following

combinations of openings:

1. Two circular openings 2" dia.
2. Two semi-circular openings 2" dia.
3. Two semi-circular openings 2" dia. and 2" dia.

It was found that the experiments were successful and that

the results were satisfactory. The results are given in the

table.

The load to be sustained by the testing jig was computed as follows:

Average minimum strain to fracture lacquer--0.001 in./in.  
Average stress in gross cross-section of plate--  
 $0.001 \times 10,300,000 = 10,300$  psi.  
Gross area of plate-- $3/16 \times 18 = 3.37$  sq. in.  
Total load-- $3.37 \times 10,300 = 34,700$  lbs.

The jig was then designed to apply this load uniformly over an 18" length without appreciable deflection. The plans for this jig are included in this paper. The load was transmitted from the jig to the plates through  $\frac{1}{2}$ " chrome steel pins fitted in machined holes  $1\frac{1}{2}$  o.c. This jig proved highly satisfactory throughout the experiments.

Average minimum value in the above range is 10.000  
 Average maximum value in the above range is 10.000  
 Average minimum value in the above range is 10.000  
 Average maximum value in the above range is 10.000

INVESTIGATION USING MODERATE  
OVEN TEMPERATURES FOR DRYING

On the advice of Prof. R. E. Trathen, the first three tests were made using the oven-drying technique which was concurrently being investigated by J. H. Wilson and B. T. Dibble. This technique was expected to give much greater sensitivity than that obtained by the usual method of air-drying the lacquer.

In this phase of the investigation the conventional method of determining and applying the proper lacquer was used. The plates and calibration bars were first coated with aluminum undercoating for all runs.

The optimum lacquer for the spraying conditions was then applied to the plates. For the first run the entire depth of the plates was sprayed to test the jig for uniform load across the edge of the plate. For the other runs the plates were sprayed only around the openings. The plates and calibration bars were then placed in the oven at the temperatures indicated. The usual steel calibration bars were used for calibrating.

After drying, the plates and calibration bars were removed from the oven and placed in the laboratory near the testing machine. At least twenty minutes elapsed before testing any plate to insure cooling to room temperature. The temperature in the laboratory during testing was recorded.



On the matter of 1901, A. B. Freeman, the first known  
person who was using the word "freedom" in the  
context of being investigated by J. E. Simon and J. E.  
Hibbs. This investigation was reported in the same  
context, then later continued by the same person of the  
investigation.

In this phase of the investigation the experimental method of determining and applying the proper treatment was used. The glass was calibrated with water first cooled with alcohol and then with alcohol.

[illegible]

After dinner, the players and spectators were  
 invited to the open air placed in the laboratory near the  
 electric machine. At least twenty minutes elapsed before  
 falling and given to those coming to see the machine.

The tests were made in a Southwark-Emery 100,000 lb. testing machine. The procedure used during testing was as follows:

A plate was inserted in the testing jig and all pins were inserted in the holes. The plate was carefully examined for crazing or cracks caused by driving the pins. An observer was stationed on each side of the plate and load was applied. A stop watch was used to clock the time from the beginning of application of load until the first cracks appeared. The time and load of the first cracks were recorded. The plate was then examined without further increase in load, and any irregularities were noted.

After examination, more load was applied in varying increments on the first run to obtain stress patterns over the whole plate. By carefully watching the lacquer at some distance from the openings it was determined that cracks appeared over the entire width of the plate at the same load. This indicated that the load was being applied uniformly at the edges, at least within the accuracy of the brittle lacquer. Photographs of the stress patterns obtained from the first run are included in a later section.

At the openings cracks would usually appear at all corners simultaneously, or nearly so. Sometimes there would be only one crack at a corner, but usually there would be two or three cracks at the first fracture. These cracks were about  $1/8$ " long. Their locations with respect to the

Following:

Testing machine. The specimens used during testing are as follows:

The tests were made in a Hotchess-Test 100,000 lb.

[illegible][illegible]

in the morning there would usually appear at all  
company's headquarters, at least in the morning, they would  
be only one group of a group, and usually there would be  
the at least one of the first persons. These persons  
were about 12" long. Their location with regard to the



corners for the various types of openings are indicated in the sketches below.



The stress concentration factors were determined from the data as follows:

The calibration strain was corrected for creep during the time of loading using the creep correction curve reproduced herein as Figure 3. This corrected strain was then multiplied by the modulus of elasticity--10,300,000 psi.--to obtain the stress at the point where the cracks occurred. The average stress over the net area of the plate was found by dividing the load on the plate at the time of the first cracks by the net area of the plate. The ratio of the stress at the cracks to the average stress is the stress concentration factor. The factors for the first three runs were then tabulated and examined.

At this point in the investigation it became apparent that the results were very low and erratic. After much deliberation it was finally decided that the procedure of using steel calibration bars and aluminum samples was decidedly faulty. Upon investigation it was determined that the linear coefficient of thermal expansion for steel was

compare the two values of  $\sigma$  and  $\sigma_0$  and find that the difference is small.



The three configurations shown are related by the following relations:

The configuration shown is related to the other two by the following relations:

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approximately  $0.0000065/^{\circ}\text{F.}$  as compared to about  $0.000013/^{\circ}\text{F.}$  for the aluminum. The effect of this difference was as follows:

After spraying, the plates and calibration bars were placed in the oven while the lacquer was in a plastic condition. During the drying period the temperature was maintained constant. Upon removing the plates and bars from the oven, however, the aluminum plates would contract much more than the steel bars. This would have the effect of placing an initial compression in the lacquer on the aluminum plates corresponding to the difference in contraction between the aluminum and the steel. This compression effect would be maintained until the plate was loaded in tension. During this time, however, the effect would be somewhat reduced by creep in the lacquer. Upon loading the plate, a greater strain would then be required to fracture the lacquer. During the time the load was being applied creep would again take place in the lacquer, this time in the opposite direction. The net effect of creep would thus be rather uncertain.

The correction to compensate for this error was made quite simply. The difference in the linear coefficients of thermal expansion of the two materials was taken as  $0.0000065/^{\circ}\text{F.}$  The difference in contractions between the two materials was this value multiplied by the temperature difference between the oven and the laboratory. This was the difference in strain induced in the lacquer by the



approximately 0.0000001, as compared to approximately 0.0000002.

For this reason, the effect of this difference was

follows:

After applying the same and calculation data were  
 placed in the same table for the purpose of a direct com-  
 parison. During the day, the temperature was fairly  
 below normal. Upon removing the glass and after the  
 over, however, the aluminum plates would conduct heat more  
 than the steel plate. This would have the effect of heating  
 in initial comparison in the liquid on the aluminum plate

corresponding to the difference in position between the

aluminum and the steel. This comparison effect would be

maintained until the glass was heated in water. During

the first, however, the effect would be somewhat reduced by

being in the liquid. Upon leaving the glass, a greater

effect would then be required to restore the liquid. During

the time the food was being applied to the glass again, the

glass in the liquid, this time in the opposite direction.

The net effect of these would not be rather uncertain.

The correction to comparison for this error was made

quite simple. The difference in the liquid coefficients of

thermal expansion of the two materials was taken as

0.0000002. The difference in coefficient of expansion was

two materials and this value multiplied by the difference

difference between the over and the liquid. This was

the difference in value caused by the liquid of the



unequal contractions of the materials. Creep was considered negligible as far as this strain was concerned. It was reasoned that whereas the time during which creep would take place to relieve the compression in the lacquer was considerably greater than that during which it would act to relieve the tension strain, since the tension strain would be much higher the net result would be unappreciable. The correction to be made was thus only the stress corresponding to the difference in contractions. This correction was applied to the creep-corrected calibration stress to obtain the actual stress at which the lacquer fractured. This procedure produced results which compared very favorably with those obtained using air-drying in the second phase of the investigation. Whereas there were certain errors in this procedure which were indeterminate, it was felt that they were of such small magnitude as not to affect the final result materially.

external conditions of the material. Given the conditions  
 possible as far as this strain was concerned. It was  
 reasoned that whereas the time during which stress would  
 take place is finite, the compression in the material was  
 continuously greater than that which would be given and so  
 relieve the tension strain, since the tension strain would  
 be much slighter and would be much less. The  
 correction to be made was that only the strain corresponding  
 to the difference in conditions. This correction was  
 applied to the wave-reversed reflection stress in order  
 the actual stress is which the tension relieved. This  
 treatment provided results which showed that the  
 with those obtained being all-right in the second place of  
 the investigation. Hence there was certain error in  
 this procedure which was indicated, it was felt that  
 they were of such small magnitude as not to affect the final  
 result materially.

### INVESTIGATION USING AIR DRYING

After consideration of the somewhat uncertain results of the first part of the investigation, the investigators decided to make several runs drying the plates in the conventional manner. The plates were coated with lacquer in the usual way, then dried at room temperature over night. The testing procedure was the same as for the previous runs.

Four runs were made in this manner, numbered 4 through 7. It was found that the calibration strains were considerably higher, but that the value of the factors did not vary beyond experimental limits. The dispersion was approximately the same as for the first three runs.

The reduced sensitivity of the lacquer when dried in air was not an inconvenience in this investigation. In fact, it may be that the results are slightly more accurate. Since the loads were higher, a small error in reading or calibration would have less effect on the factor.

This part of the investigation served mainly as a check on the first part and to obtain additional values to compute the mean factors. The results compared favorably with those obtained in the first three runs.



[illegible]



THE USE OF HIGHER TEMPERATURES IN CON-  
JUNCTION WITH ANOTHER RESEARCH PROJECT

The next three runs, numbers 8, 9, and 10, were carried on in conjunction with a contemporary research project on the heat treatment of brittle lacquer by Lieutenants (junior grade) B. T. Dibble and J. N. Wilson, Civil Engineer Corps, U. S. Navy at R.P.I. These officers investigated the use of heat treatment to sensitize the lacquer and had at this time obtained sets of optimum conditions of lacquer numbers with corresponding degrees of heat treatment. It was desired to test these conditions of heat treatment on the complicated shapes and the practical problem of this stress concentration project. As indicated in runs 1, 2, and 3 of this project the Dibble-Wilson heat treatment of the test plates was used but at that early date a final set of optimum conditions had not been obtained and the investigation of this project showed a return to the standard method of air drying would be advisable.

Three sets of optimum conditions as suggested by Dibble and Wilson were set up for the same group of plates. The plates were sprayed, heat treated and tested with a run for each of the three sets of conditions. These runs are the following runs designated as numbers 8, 9, and 10.

The next item was the report of the committee on the subject of the investigation of the activities of the Communist Party in the United States. The committee reported that it had held several public hearings and had received many suggestions from the public. It had also conducted extensive research into the activities of the Communist Party and its various fronts. The committee concluded that the Communist Party was a serious threat to the national security and recommended that the government take prompt action to counter its activities. The report was well received by the audience and led to a discussion of the need for vigilance against subversion.

Three sets of engine conditions are suggested by

Run #8 consisted of plates, 1, 2, 3, and 4, the semi-ellipse group, sprayed with lacquer number 1205, heat treated for 28 hours in the oven at  $124^{\circ}\text{F.}$ , and slowly cooled to room temperature. Run #9 consisted of the same set of plates but with lacquer #1201 and oven temperature of  $168^{\circ}\text{F.}$  Run #10 was with same plates using lacquer #1203 and oven temperature  $148^{\circ}\text{F.}$

These three separate runs served to confirm the Dibble-Wilson conclusions of increased sensitivity, with heat treatment which will undoubtedly be a tremendous stride in the success of brittle lacquers. However, this increased sensitivity for this one particular project on stress concentrations did not materially aid in the determinations of the factors. In run #8 the lacquer was so sensitive that the impact of driving the pins to set the plate in the jig produced small cracks at the critical points of the openings which again was proof of the increased sensitivity but which was undesirable for this project in that the resulting stress concentration factor for each plate in each run hinged on the accurate observation of the first minute crack in the lacquer under load.

The second apparent disadvantage of using heat treatment for this project was the necessity of using a calculated correction for the difference in coefficients of expansion between the aluminum test plates and the steel calibration strips. This calculated temperature correction stress at the



and he consisted of plates 1, 2, 3, and 4, the same-  
 slight group, arranged with legend number 1000, and  
 listed for 10 years in the case of 1940, and listed  
 under the term "vegetation". The 10 consisted of the same  
 set of plates but with legend 1001 and other legends  
 of 1940, and 10 was the same plates being used 1900  
 and other legends 1900.

These plates were used to produce the photo-  
 graph collection of historical material, with other-  
 best which will undoubtedly be a tremendous value in the  
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high oven temperature runs far outweighed the stress for the calibrated strain which was undesirable. For example, in run #9 the temperature correction amounted to 8170 psi while the stress obtained from the creep corrected calibration bar strain was only 3040 psi. An attempt was made to eliminate the necessity of this correction by the preparation of aluminum calibration strips, however the aluminum strips were of insufficient strength to withstand the deflection of the calibrator cam and all bars were permanently deformed. Had there been time available a new cam for the calibrator could have been prepared to give a much smaller deflection, therefore allowing the use of aluminum. Another possible remedy would have been to use calibration strips of 75 ST aluminum which has a yield strength of approximately 80,000 psi and could have withstood the deflection. Again the unavailability of materials and lack of time prevented this refinement.

A third disadvantage of these high heat treatments was the wide dispersion of results obtained as noted in the data for the three runs.

[illegible]

The wide distribution of certain diseases is noted in the following table.

### CONCLUSIONS

The average values for the stress concentration factors and the maximum dispersions for the ten plates tested are tabulated below.

	Factor	Dispersion
Plate 1--single semi-ellipse	3.23	24.7%
2--two semi-ellipses 5" o.c.	2.60	18.5%
3--two semi-ellipses 6" o.c.	2.66	12.0%
4--two semi-ellipses 7" o.c.	3.04	18.5%
5--single bi-ellipse	3.28	20.5%
6--two bi-ellipses 5" o.c.	2.84	18.5%
7--two bi-ellipses 6" o.c.	2.63	25.0%
8--two bi-ellipses 7" o.c.	2.80	19.0%
9--single circular hole	1.94	11.3%
10--three circular holes 3" o.c.	1.82	20.3%

The conclusions which the authors have drawn from the above results and the experiment as a whole are as follows:

- (1) brittle lacquer is an excellent means for determining stress patterns in plates with openings.
- (2) brittle lacquer is an excellent means for locating points of stress concentration.
- (3) the dispersion may be as great as 25%, with occasional errors of much greater magnitude.
- (4) the stress concentration factors obtained by the use of the brittle lacquer technique are definitely lower than theoretical values or other available experimental values. For instance, the graph on page 3 gives a factor of about 2.6 for the opening in plate #9 as compared to an average value of 1.94 obtained by the brittle lacquer technique. It is believed that the factors for the elliptical openings are considerably lower than theoretical.



# TABLE III

THE MEAN SQUARES FOR THE LINEAR REGRESSION  
 FACTORS AND THE MEAN SQUARES FOR THE LINEAR  
 FACTORS ARE LISTED BELOW.

Regression	Factor	Mean Square
10.75	1--single seedlings	5.55
10.35	2--two seedlings	5.00
12.00	3--two seedlings	5.55
11.55	4--two seedlings	5.00
10.55	5--single seedlings	5.55
10.55	6--two seedlings	5.55
10.55	7--two seedlings	5.00
10.55	8--two seedlings	5.55
11.55	9--single seedlings	5.55
10.55	10--two seedlings	5.55

The mean squares for the factors are listed below and the regression as a whole are as follows:

(1) Factor 1--single seedlings is an excellent means for determining which factors are listed with regression.

(2) Factor 2--two seedlings is an excellent means for determining which factors are listed with regression.

(3) The regression may be as high as 50% with regression factors of each factor mentioned.

(4) The mean square regression factors obtained by the use of the single seedlings factors are listed below. They show that statistical values of other factors are not significant. For instance, available experimental data. For instance, the factor in the 2 factor a factor of about 2.5 has been found in the 10 as compared to the average value of 1.00 obtained by the single seedlings factor. It is observed that the factors for the statistical regression are considered to be significant.



- (5) the tests showed that there was no noticeable variation in factors in the inside and outside corners of the openings in a plate.
- (6) there is no appreciable difference between the factors for semi-ellipses and bi-ellipses.
- (7) the factors seemed to vary according to this rule: a single opening causes the highest factor. For two openings the factor increases with the distance between the openings. For the openings tested all the factors for two openings were less than those for one. It seems likely that the factor for two openings would approach that for one opening as the distance between openings increases, but this was not definitely determined.
- (8) the shape of the stress pattern is affected by the curvature of the opening. Comparing figures 7, 13, and 14, one can see that as the curvature increases the isoentatic moves outward from the curved portion of the opening. This effect is most noticeable on Figure 7, the semi-ellipse. The isoentatics in this case are extended much farther above the curved portion than below the straight bottom of the opening. A study of this phenomenon was outside the scope of this investigation. Such a study might, however, throw considerable light on the effect of openings in plates.

The reason for the low values of stress concentration factors has not been determined. One possible solution is that the lacquer was thin over the edges of the openings and would therefore not fracture at as low a strain as the lacquer on the calibration bars. However, every possible means was taken to obtain a uniform thickness of lacquer at all points around the opening. The investigators are of the opinion that this did not have an appreciable effect on the factors obtained, but was mentioned merely to caution other investigators to use great care in applying the lacquer around openings.



Another possible cause of the low values obtained was the discontinuity of the lacquer near the edges of the openings. As far as can be determined from observing carefully the cracks on calibration bars it seemed that lacquer cracked at the edges of the bars at the same strain as in the body of the lacquer itself. However, this has not been thoroughly investigated and no definite statements can be made concerning it.

The great difficulty in this work is that the stress drops off so rapidly near the opening that a value obtained at only a minute distance from the opening would be considerably in error. As far as could be determined the stresses obtained in this investigation were the correct values, but perhaps there was some source of error at this critical point which has not as yet been recognized. It was felt that this is a particularly important phase of the use of brittle lacquer and would be a worthwhile problem for future investigation.

Any readers making a comparison of these factors with others are cautioned that these factors are based on the net area and not on gross area. Factors based on net area will be smaller than factors based on gross area.







### SUGGESTIONS FOR FUTURE INVESTIGATION

The following suggestions for future investigation are set down by the authors:

- (1) The investigation of stress concentration factors for plates in compression might yield valuable information about the problem. Such an investigation would require special equipment and considerable time. The method of spraying while plate is under a compressive load, drying under load, and testing by relaxing load could be used.
- (2) An investigation using a jig which would clamp the plates would eliminate some of the troubles experienced from driving the pins in this investigation, therefore the increased sensitivity of heat treatment could be used.
- (3) The development of a technique which would guarantee a uniform thickness of lacquer inside and at the edges of the openings would probably yield more reliable results than the usual technique. A finer lower pressure spray or perhaps a brush could be used.
- (4) A study of the variation of stress concentration factors over a wider range of pillar depths would be of great value.
- (5) An investigation of the same openings using the photoelastic technique would be a valuable check on the results obtained.
- (6) In association with heat treatment the preparation of calibration strips of the same material as the test plates with possible pre-requisite preparation of a calibrator cam to give small deflections would eliminate the need of the large thermal expansion corrections that were necessary in this particular experiment. Or the preparation of calibration strips of 75 ST aluminum to withstand the deflection of the calibrator cam could likewise be done for use with aluminum plates.

RECOMMENDATIONS FOR FURTHER INVESTIGATION

The following suggestions for further investigation

are set down in the following:

- (1) The investigation of stress concentration factors for stress in the vicinity of the hole in the plate. This investigation should be made in the form of a series of experiments in which the hole is made of different sizes and shapes. The results of these experiments should be compared with the results of the theoretical calculations. The results of these experiments should be compared with the results of the theoretical calculations.
- (2) The investigation of the effect of the hole on the stress distribution in the plate. This investigation should be made in the form of a series of experiments in which the hole is made of different sizes and shapes. The results of these experiments should be compared with the results of the theoretical calculations. The results of these experiments should be compared with the results of the theoretical calculations.
- (3) The investigation of the effect of the hole on the stress distribution in the plate. This investigation should be made in the form of a series of experiments in which the hole is made of different sizes and shapes. The results of these experiments should be compared with the results of the theoretical calculations. The results of these experiments should be compared with the results of the theoretical calculations.
- (4) The investigation of the effect of the hole on the stress distribution in the plate. This investigation should be made in the form of a series of experiments in which the hole is made of different sizes and shapes. The results of these experiments should be compared with the results of the theoretical calculations. The results of these experiments should be compared with the results of the theoretical calculations.
- (5) The investigation of the effect of the hole on the stress distribution in the plate. This investigation should be made in the form of a series of experiments in which the hole is made of different sizes and shapes. The results of these experiments should be compared with the results of the theoretical calculations. The results of these experiments should be compared with the results of the theoretical calculations.
- (6) The investigation of the effect of the hole on the stress distribution in the plate. This investigation should be made in the form of a series of experiments in which the hole is made of different sizes and shapes. The results of these experiments should be compared with the results of the theoretical calculations. The results of these experiments should be compared with the results of the theoretical calculations.

# DESCRIPTIONS OF TEST PLATES

<u>Plate No.</u>	<u>Average Thickness</u>	<u>Gross Width</u>	<u>Net Width</u>	<u>Gross Area</u>	<u>Net Area</u>
1	0.1870	15.88	12.75	2.97	2.39
2	0.1870	15.88	9.75	2.97	1.62
3	0.1880	15.88	9.81	2.90	1.64
4	0.1865	18.06	11.94	3.37	2.23
5	0.1865	15.88	12.81	2.96	2.38
6	0.1880	15.88	9.91	2.90	1.86
7	0.1885	18.06	12.00	3.41	2.27
8	0.1870	18.00	11.94	3.37	2.23
9	0.1870	15.88	14.38	2.97	2.69
10	0.1885	15.88	11.38	2.00	1.15

Plate No. 1 has one Semi-ellipse, centered

Plate No. 2 has two Semi-ellipses, 5"o.c.

Plate No. 3 has two Semi-ellipses, 6"o.c.

Plate No. 4 has two Semi-ellipses, 7"o.c.

Plate No. 5 has one Bi-ellipse, centered

Plate No. 6 has two Bi-ellipses, 5"o.c.

Plate No. 7 has two Bi-ellipses, 6"o.c.

Plate No. 8 has two Bi-ellipses, 7"o.c.

Plate No. 9 has one Circle, centered

Plate No. 10 has three Circles, 3"o.c.



# Table 1. Summary of data for the 10 cases.

Case No.	1	2	3	4	5	6	7	8	9	10
Age	45	50	55	60	65	70	75	80	85	90
Sex	M	F	M	F	M	F	M	F	M	F
Height (cm)	170	165	175	160	180	155	185	150	190	145
Weight (kg)	70	65	75	60	80	55	90	50	100	45
Blood Pressure (mmHg)	120/80	130/90	110/70	140/100	100/60	150/110	90/50	160/120	80/40	170/130
Heart Rate (b/min)	70	75	65	80	60	85	55	90	50	95
ECG	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
X-ray	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
CT Scan	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
MRI	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Biopsy	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Pathology	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal	Normal
Prognosis	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Treatment	None	None	None	None	None	None	None	None	None	None
Follow-up	1 year	1 year	1 year	1 year	1 year	1 year	1 year	1 year	1 year	1 year
Outcome	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good

Table 1. Summary of data for the 10 cases. The table shows the following information for each case: Case No., Age, Sex, Height (cm), Weight (kg), Blood Pressure (mmHg), Heart Rate (b/min), ECG, X-ray, CT Scan, MRI, Biopsy, Pathology, Prognosis, Treatment, Follow-up, and Outcome. The data is presented in a tabular format with 11 columns and 17 rows. The first row is the header, and the subsequent rows contain the data for each case. The data is as follows:

Case No.	Age	Sex	Height (cm)	Weight (kg)	Blood Pressure (mmHg)	Heart Rate (b/min)	ECG	X-ray	CT Scan	MRI	Biopsy	Pathology	Prognosis	Treatment	Follow-up	Outcome
1	45	M	170	70	120/80	70	Normal	Normal	Normal	Normal	Normal	Normal	Good	None	1 year	Good
2	50	F	165	65	130/90	75	Normal	Normal	Normal	Normal	Normal	Normal	Good	None	1 year	Good
3	55	M	175	75	110/70	65	Normal	Normal	Normal	Normal	Normal	Normal	Good	None	1 year	Good
4	60	F	160	60	140/100	80	Normal	Normal	Normal	Normal	Normal	Normal	Good	None	1 year	Good
5	65	M	180	80	100/60	60	Normal	Normal	Normal	Normal	Normal	Normal	Good	None	1 year	Good
6	70	F	155	55	150/110	85	Normal	Normal	Normal	Normal	Normal	Normal	Good	None	1 year	Good
7	75	M	185	90	90/50	55	Normal	Normal	Normal	Normal	Normal	Normal	Good	None	1 year	Good
8	80	F	150	50	160/120	90	Normal	Normal	Normal	Normal	Normal	Normal	Good	None	1 year	Good
9	85	M	190	100	80/40	50	Normal	Normal	Normal	Normal	Normal	Normal	Good	None	1 year	Good
10	90	F	145	45	170/130	95	Normal	Normal	Normal	Normal	Normal	Normal	Good	None	1 year	Good

## OBSERVED DATA

Run #1

July 28, 1948

All plates coated with #1207; dried 20 hours in oven at 90°F.  
Room temperature during test 70°F.

Calibrations: 6.61, 6.57

average  $6.09 \times 10^{-4}$ 

Plate	Load to heading	Time Sec.	Average Stress- Net Area	Corrected* Stress at Cracks	Factor
1	7550	1320	3160	10,940	3.47
2	4230	1140	4230	10,840	2.87
3	6500	80	3520	8780	2.62
4	7500	70	3370	8670	2.57
5	10,500	270	2510	8560	3.23
6	8000	90	4300	8880	2.07
7	10,000	150	4420	8980	2.03
8	8500	90	3800	8880	2.33
9	10,600	60	3950	8550	2.16
10	4000	30	1880	8370	4.48

\* Corrected stress includes the following corrections:

- (1) for difference in coefficients of thermal expansion of steel calibration strip and aluminum test plates during cooling from 90°F. (oven temperature) to 70°F. (room temperature).

$$\text{Correction} = 65 \times 10^{-7} \times 10.3 \times 10^6 \times 20 = 1340 \text{ psi}$$

- (2) for creep during time of test, obtained from creep curves.

Sample: Plate No. 1.

Calibration strain is  $6.09 \times 10^{-4}$  inches/inch.

Strain corrected for creep during 1320 seconds is  $9.30 \times 10^{-4}$  inches/inch.

Corresponding stress  $9.30 \times 10^{-4} \times 10.3 \times 10^6 = 9600 \text{ psi}$

Stress corrected for temperature =  $9600 + 1340 = 10,940 \text{ psi}$ .

1. The following is a list of the names of the persons who have been identified as having been in contact with the subject of this investigation, and who have been identified as having been in contact with the subject of this investigation, and who have been identified as having been in contact with the subject of this investigation.

(S) For group sailing ship at 1000. Estimated 1000. 1000.

4. The following table shows the number of people who attended the concert in each age group.



## OBSERVED DATA

Run #2

July 29, 1948

All plates coated with #1207; dried 20 hours in oven at 110°F.  
 Room temperature 77°F.

Calibrations: 2.08, 3.08

average  $2.58 \times 10^{-4}$ 

<u>Plate</u>	<u>Load to Reading</u>	<u>Time Sec.</u>	<u>Average Stress- Net Area</u>	<u>Corrected* Stress at Cracks</u>	<u>Factor</u>
1	6400	150	2680	5590	2.07
2	2500	5	1370	4910	3.58
3	2400	45	1310	5010	3.83
4	3500	60	1570	5350	3.41
5	4200	60	1750	5350	3.05
6	2500	75	1345	5400	4.01
7	5000	50	2190	5020	2.29
8	4000	150	1790	5590	3.11
9	No readings -- badly crazed.				
10	4500	30	2090	5220	2.50

\* See Run #1

# TABLE 1

1964, 1965, 1966

1967, 1968

All data were obtained from the same source, and are based on the same methods of collection and analysis.

1964, 1965, 1966

1967, 1968

Year	1964	1965	1966	1967	1968	1969
1	100	100	100	100	100	100
2	100	100	100	100	100	100
3	100	100	100	100	100	100
4	100	100	100	100	100	100
5	100	100	100	100	100	100
6	100	100	100	100	100	100
7	100	100	100	100	100	100
8	100	100	100	100	100	100
9	100	100	100	100	100	100
10	100	100	100	100	100	100

1969, 1970

## OBSERVED DATA

Run #3

July 29, 1948

All plates coated with #1208; dried 20 hours in oven at 100°F.  
 Room temperature 80°F.

Calibrations: 3.1, 3.6

average  $3.35 \times 10^{-4}$ 

<u>Plate</u>	<u>Load to Reading</u>	<u>Time Sec.</u>	<u>Average Stress- Net Area</u>	<u>Corrected* Stress at Cracks</u>	<u>Factor</u>
1	3900	15	1630	5140	3.15
2	4600	36	2520	5280	2.12
3	3400	20	1840	5180	2.88
4	2300	8	1030	5020	4.88
5	3200	9	1330	5020	3.77
6	3800	25	2040	5210	2.56
7	4000	17	1760	5140	2.93
8	4400	35	1960	5320	2.72
9	5300	10	1960	5070	2.06
10	5600	30	2600	5280	2.02

\* See Run #1



# GRAVITY DATA

July 29, 1948

Run 15

All points covered with 11805; 0145 to 0155 in zone of 100'.  
 Hole completed 80'.  
 Directional: 3.1, 3.6

average 3.35 x 10<sup>-4</sup>

Time	Low to	Average	Corrected	Factor
Sec.	Reading	Net Area	Area at	
15	3400	1550	5140	3.15
20	4000	2250	5280	3.18
25	4600	2950	5420	3.22
30	5200	3650	5560	3.25
35	5800	4350	5700	3.28
40	6400	5050	5840	3.31
45	7000	5750	5980	3.34
50	7600	6450	6120	3.37
55	8200	7150	6260	3.40
60	8800	7850	6400	3.43
65	9400	8550	6540	3.46
70	10000	9250	6680	3.49
75	10600	9950	6820	3.52
80	11200	10650	6960	3.55
85	11800	11350	7100	3.58
90	12400	12050	7240	3.61
95	13000	12750	7380	3.64
100	13600	13450	7520	3.67

\* see Run 11

## OBSERVED DATA

Run #4

August 3, 1948

All plates coated with #1208; dried 26 hours at room temperature.

Calibrations: 5.8, 6.1

average  $5.95 \times 10^{-4}$ 

<u>Plate</u>	<u>Load to Reading</u>	<u>Time Sec.</u>	<u>Average Stress-Net Area</u>	<u>Stress at Cracks</u>	<u>Factor</u>
1	5100	19	2130	6800	3.18
2	4600	22	2520	6870	2.72
3	5200	10	2820	6820	2.34
4	5800	23	2800	6870	2.63
5	5150	25	2160	6870	3.16
6	5040	25	2720	6870	2.52
7	6200	32	2720	6380	2.34
8	6000	28	2690	6300	2.34
9	10,800	42	4020	7110	1.77
10	9800	12	4560	6620	1.45

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DATE 01-10-2001 BY 60322 UCBAW

Year	1990	1991	1992	1993	1994
1990	1.00	1.00	1.00	1.00	1.00
1991	1.00	1.00	1.00	1.00	1.00
1992	1.00	1.00	1.00	1.00	1.00
1993	1.00	1.00	1.00	1.00	1.00
1994	1.00	1.00	1.00	1.00	1.00



## OBSERVED DATA

Run #5

August 6, 1948

All plates coated with #1206; dried 17 hours at room temperature.

Calibration:  $7.32 \times 10^{-4}$

<u>Plate</u>	<u>Load to Reading</u>	<u>Time Sec.</u>	<u>Average Stress- Net Area</u>	<u>Stress at Cracks</u>	<u>Factor</u>
1	8500	60	3570	8900	2.49
2	6100	14	3350	8210	2.45
3	5600	22	3040	8450	2.78
4	7100	60	3180	8900	2.80
5	8100	60	3400	8900	2.61
6	5800	25	3110	8450	2.71
7	6700	23	2940	8450	2.87
8	6100	20	2740	8390	3.05
9	14,000	66	5210	9000	1.72
10	11,200	22	5220	8450	1.61

11/11/1964

<sup>10</sup> Of a 34.5% probability.

Class	Lead to Footing	Time Sec.	Average Rate Per Hour	Distance of Crews	Factor
1	3400	40	5000	5000	1.48
2	4100	44	3750	5510	2.45
3	5000	50	3000	6450	3.78
4	6100	60	1750	6900	5.60
5	8100	80	2400	7900	8.01
6	9300	95	1710	8450	9.71
7	9700	100	1640	8450	10.59
8	8100	100	2740	8500	12.06
9	14,000	100	1010	9000	17.76
10	11,500	100	1440	9400	17.98

## OBSERVED DATA

Run #6

August 7, 1948

All plates coated with #1206; dried 26 hours at room temperature.

Calibration:  $8 \times 10^{-4}$ 

<u>Plate</u>	<u>Load to Heading</u>	<u>Time Sec.</u>	<u>Average Stress Net Area</u>	<u>Stress at Cracks</u>	<u>Factor</u>
1	6100	32	2550	9410	3.70
2	6000	26	3220	9270	2.87
3	6200	31	3370	9350	2.77
4	6300	30	2830	9300	3.30
5	6400	22	2670	9270	3.45
6	7100	31	3820	9350	2.44
7	8000	24	3820	9270	2.63
8	6100	18	2720	9090	3.33
9	13,100	50	4880	9670	1.98
10	9200	30	4270	9300	2.18



Year	Population	Area	Population	Area	Year
1970	1000	1000	1000	1000	1970
1971	1000	1000	1000	1000	1971
1972	1000	1000	1000	1000	1972
1973	1000	1000	1000	1000	1973
1974	1000	1000	1000	1000	1974
1975	1000	1000	1000	1000	1975
1976	1000	1000	1000	1000	1976
1977	1000	1000	1000	1000	1977
1978	1000	1000	1000	1000	1978
1979	1000	1000	1000	1000	1979
1980	1000	1000	1000	1000	1980

## OBSERVED DATA

Run #7

August 10, 1948

All plates coated with #1205; dried 28 hours at room temperature.

Calibration:  $8.26 \times 10^{-4}$ 

<u>Plate</u>	<u>Load to Reading</u>	<u>Time Sec.</u>	<u>Average Stress- Net Area</u>	<u>Stress at Cracks</u>	<u>Factor</u>
1	5800	25	2420	8150	3.37
2	5100	21	2800	8120	2.90
3	6100	30	3310	8300	2.49
4	5100	20	2280	8090	3.51
5	5400	19	2250	8090	3.58
6	5100	19	2740	8090	2.94
7	5600	21	2460	8120	3.29
8	6800	32	3040	8300	2.73
9	6600	29	2450	8300	3.38
10	9800	48	4560	8450	1.85

# CONCRETE DATA

August 10, 1948

Run 7

All trials coated with 1100; dried 10 hours at room temperature.

Collapsions: 0.10 x 10<sup>-3</sup>

1100	Load to collapse	Time sec.	Average strain- rate in in./in.	Strain at collapse	Factor
1	1000	25	0.000	0.110	1.00
2	1100	31	0.000	0.110	1.00
3	1100	30	0.000	0.110	1.00
4	1100	40	0.000	0.110	1.00
5	1100	19	0.000	0.110	1.00
6	1100	19	0.000	0.110	1.00
7	1100	21	0.000	0.110	1.00
8	1100	25	0.000	0.110	1.00
9	1100	29	0.000	0.110	1.00
10	1100	48	0.000	0.110	1.00

## OBSERVED DATA

Run #8

August 12, 1948

Plates 1, 2, 3, and 4 coated with #1205; heat treated at 124°F. for 28 hours. Room temperature 78°F.

Calibration:  $2.0 \times 10^{-4}$

<u>Plate</u>	<u>Load to Reading</u>	<u>Time Sec.</u>	<u>Average Stress- Net Area</u>	<u>Corrected* Stress at Cracks</u>	<u>Factor</u>
1	3000	9	1250	5290	4.23
2	3500	17	1920	5350	2.78
3	4200	27	2280	5410	2.37
4	2800	9	1270	5290	4.16

\* See Run #1



# STANDARD DATA

August 11, 1966

and 18

Wicks J. J. and J. J. Wicks with J. J. Wicks and J. J. Wicks  
124° E. for 60 miles. From Washington 107°.

Calibration:  $2.0 \times 10^{-4}$

Time	Rate	Count Rate	Count Rate	Count Rate	Count Rate
sec.	sec.	sec.	sec.	sec.	sec.
1	1000	1000	1000	1000	1000
2	1000	1000	1000	1000	1000
3	1000	1000	1000	1000	1000
4	1000	1000	1000	1000	1000
5	1000	1000	1000	1000	1000
6	1000	1000	1000	1000	1000
7	1000	1000	1000	1000	1000
8	1000	1000	1000	1000	1000
9	1000	1000	1000	1000	1000
10	1000	1000	1000	1000	1000
11	1000	1000	1000	1000	1000
12	1000	1000	1000	1000	1000
13	1000	1000	1000	1000	1000
14	1000	1000	1000	1000	1000
15	1000	1000	1000	1000	1000
16	1000	1000	1000	1000	1000
17	1000	1000	1000	1000	1000
18	1000	1000	1000	1000	1000
19	1000	1000	1000	1000	1000
20	1000	1000	1000	1000	1000
21	1000	1000	1000	1000	1000
22	1000	1000	1000	1000	1000
23	1000	1000	1000	1000	1000
24	1000	1000	1000	1000	1000
25	1000	1000	1000	1000	1000
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27	1000	1000	1000	1000	1000
28	1000	1000	1000	1000	1000
29	1000	1000	1000	1000	1000
30	1000	1000	1000	1000	1000
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32	1000	1000	1000	1000	1000
33	1000	1000	1000	1000	1000
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36	1000	1000	1000	1000	1000
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38	1000	1000	1000	1000	1000
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40	1000	1000	1000	1000	1000
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49	1000	1000	1000	1000	1000
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85	1000	1000	1000	1000	1000
86	1000	1000	1000	1000	1000
87	1000	1000	1000	1000	1000
88	1000	1000	1000	1000	1000
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91	1000	1000	1000	1000	1000
92	1000	1000	1000	1000	1000
93	1000	1000	1000	1000	1000
94	1000	1000	1000	1000	1000
95	1000	1000	1000	1000	1000
96	1000	1000	1000	1000	1000
97	1000	1000	1000	1000	1000
98	1000	1000	1000	1000	1000
99	1000	1000	1000	1000	1000
100	1000	1000	1000	1000	1000

## OBSERVED DATA

Run #9

August 17, 1948

Plates 1 to 4 coated with #1201; heat treated 20 hours in oven at 168°F. Cooled in oven to room temperature 76°F.

Calibration:  $2.7 \times 10^{-4}$  inches/inch

Plate	Load to Reading	Time Sec.	Average Stress- Net Area	Corrected* Stress at Cracks	Factor
1	2600	13	1090	9210	8.47
2	3000	16	1650	9240	5.60
3	2000	8	1080	9150	8.48
4	3000	21	1340	9280	6.92

\* See Run #1

# RESEARCH 1924

August 14, 1940

Wm. V.

Plots 1 to 4 covered with 1/2 inch of water in  
even at 100 ft. level in view of some irregularities in

Water level: 1.5 ft. to 10 ft. irregularities

Time	Lowest Reading	Time	Lowest Reading	Time	Lowest Reading
1	1000	12	1000	13	1000
2	1000	14	1000	15	1000
3	1000	16	1000	17	1000
4	1000	18	1000	19	1000

W. V. 1940

## OBSERVED DATA

Run #10

August 18, 1948

Plates 1 to 4 coated with #1203; heat treated 20 hours in oven at 148°F. Cooled in oven to room temperature of 76°F.

Calibration:  $4.6 \times 10^{-4}$  inches/inch

Plate	Load to Reading	Time Sec.	Average Stress-Net Area	Corrected <sup>*</sup> Stress at Cracks	Factor
1	4900	31	2050	10,230	5.00
2	5300	20	2920	10,100	3.47
3	5000	22	2720	10,140	3.71
4	4400	32	1970	10,230	5.20

\* See Run #1



# RECEIVED

January 10, 1945

San Jo

Placed in to a sealed with glass; heat treated in water at 150°C. - tested in order to determine properties of YAG.

Calculation:  $4.8 \times 10^{-8}$  sec/cm<sup>2</sup>

Plate	Load to fracture	Time (sec.)	Average stress - psi	Calculated stress in psi	Factor
1	4500	22	2000	10,100	5.05
2	4700	20	2040	10,140	5.07
3	4900	20	2100	10,140	5.11
4	4400	20	1970	10,140	5.15

San Jo

## COMPUTATION AND COMPARISONS OF FINAL FACTORS

Plate	Runs							Total	Average
	I	II	III	IV	V	VI	VII		
1	3.47	2.07*	3.15	3.18	2.49	3.70	3.37	19.36	3.23
2	2.57	3.58*	2.12	2.72	2.45	2.87	2.90	15.63	2.60
3	2.69	3.83*	2.88	2.34	2.78	2.77	2.49	15.95	2.66
4	2.57	3.41	4.88*	2.63	2.80	3.30	3.51	18.22	3.04
5	3.33	3.05	3.77	3.16	2.61	3.45	3.58	22.95	3.28
6	2.07	4.01*	2.56	2.52	2.71	2.44	2.94	15.24	2.54
7	2.03	2.29	2.93	2.34	2.87	2.63	3.29	18.38	2.63
8	2.33	3.11	2.72	2.34	3.05	3.33	2.73	19.61	2.80
9	2.16	----	2.06	1.77	1.72	1.98	3.38*	9.69	1.94
10	<u>4.48*</u>	<u>2.50*</u>	<u>2.02</u>	<u>1.45</u>	<u>1.61</u>	<u>2.18</u>	<u>1.85</u>	<u>9.11</u>	<u>1.82</u>
Total									
(1-8)	21.06	11.86	20.13	21.23	21.76	24.39	24.61		
Ave.	2.63	2.96	2.88	2.65	2.72	3.05	3.08		

\* This value arbitrarily discarded as it differed from the mean for the plate by more than twenty-five per cent.

# COMPARISON OF MEAN VALUES

Class	I	II	III	IV	V	VI	VII	VIII	Total
1	2.47	2.07	2.18	2.18	2.49	2.10	2.07	2.07	2.18
2	2.07	2.08	2.18	2.18	2.18	2.18	2.18	2.18	2.18
3	2.08	2.08	2.18	2.18	2.18	2.18	2.18	2.18	2.18
4	2.07	2.11	2.18	2.18	2.18	2.18	2.18	2.18	2.18
5	2.08	2.08	2.18	2.18	2.18	2.18	2.18	2.18	2.18
6	2.07	2.07	2.18	2.18	2.18	2.18	2.18	2.18	2.18
7	2.07	2.07	2.18	2.18	2.18	2.18	2.18	2.18	2.18
8	2.07	2.11	2.18	2.18	2.18	2.18	2.18	2.18	2.18
9	2.18	---	2.08	2.18	2.18	2.18	2.18	2.18	2.18
10	2.08	2.08	2.18	2.18	2.18	2.18	2.18	2.18	2.18
Total	21.08	21.08	21.08	21.08	21.08	21.08	21.08	21.08	21.08
Mean	2.11	2.11	2.11	2.11	2.11	2.11	2.11	2.11	2.11

\* This value indicates as it differs from the mean for the class of more than twenty-five per cent.

### EXPLANATION OF PHOTOGRAPHS ON FOLLOWING PAGES

Some of the following photographs were made of the test plates after a test run. A red dye etchant was used to accentuate the small cracks for better photographing purposes.

The photographs are primarily to show the stress distribution over the area surrounding the openings. For the actual calculation of the concentration factors only the first minute crack was necessary but the crack was too small to be photographed. Some photographs show the isoentatics for various loads and some clearer photographs show the isostatics. An isoentatic is a line drawn to join the ends of the cracks (isostatics) in the lacquer, thus is the locus of points of equal strain. An isostatic is an actual crack in the lacquer or the lines of failure of the coating. The directions of the principal stresses are tangent and perpendicular to the isostatics.<sup>1</sup> See Figure 14 for procedure for obtaining isoentatics.

1. A. J. Durelli, "What Kind of Information Does Brittle Lacquer Give", Product Engineering, June, 1948.



THEORY OF PHOTOGRAPHY IN POLARIS

Some of the following photographs were made of the  
first plates after a test run. A red dye was used  
to accentuate the small cracks for better photographing  
purpose.

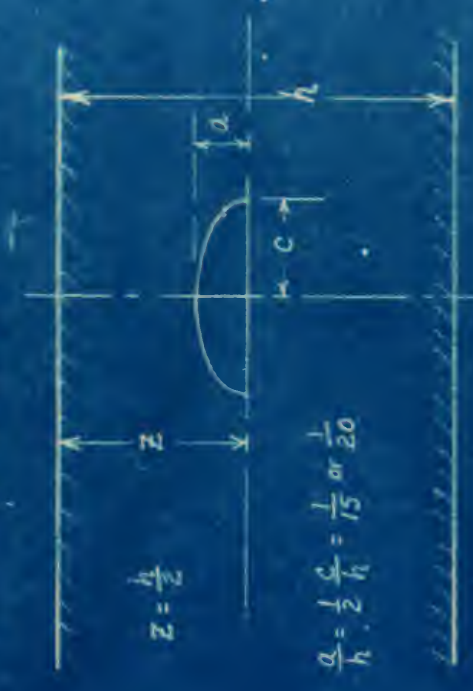
The photographs are arranged in order to show the  
distribution over the area surrounding the opening. For  
the actual calculation of the concentration of stress  
the first plate was necessary but the stress was too  
small to be photographed. Some photographs show the  
surface for various loads and some electrical photographs show  
the isotherms. An isotherm is a line drawn to join the  
ends of the isotherms (isotherms) in the liquid, and is the  
line of points of equal stress. An isotherm is an actual  
space in the liquid on the lines of isotherms of the cooling.  
The directions of the principal stresses are shown and  
perpendicular to the isotherms. The stress is for purposes  
for obtaining isotherms.

# RELATIVE DIMENSIONS OF PLATES AND OPENINGS

(A) CIRCULAR OPENINGS



(B) HALF-ELLIPTICAL OPENINGS, STRAIGHT BOTTOM



(C) HALF-ELLIPTICAL OPENINGS, CURVED BOTTOM



(D) PILLARS

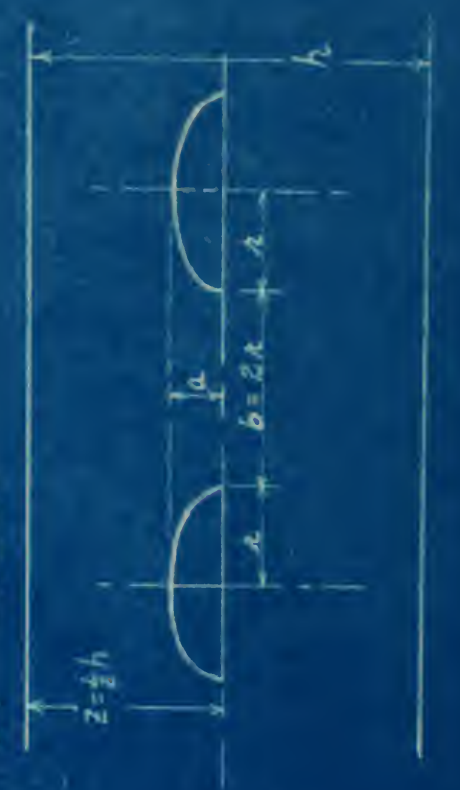


FIG. 1











# STRESSCOAT CREEP CORRECTION CHART - I

Strain - in. per in.  $\times 10^4$

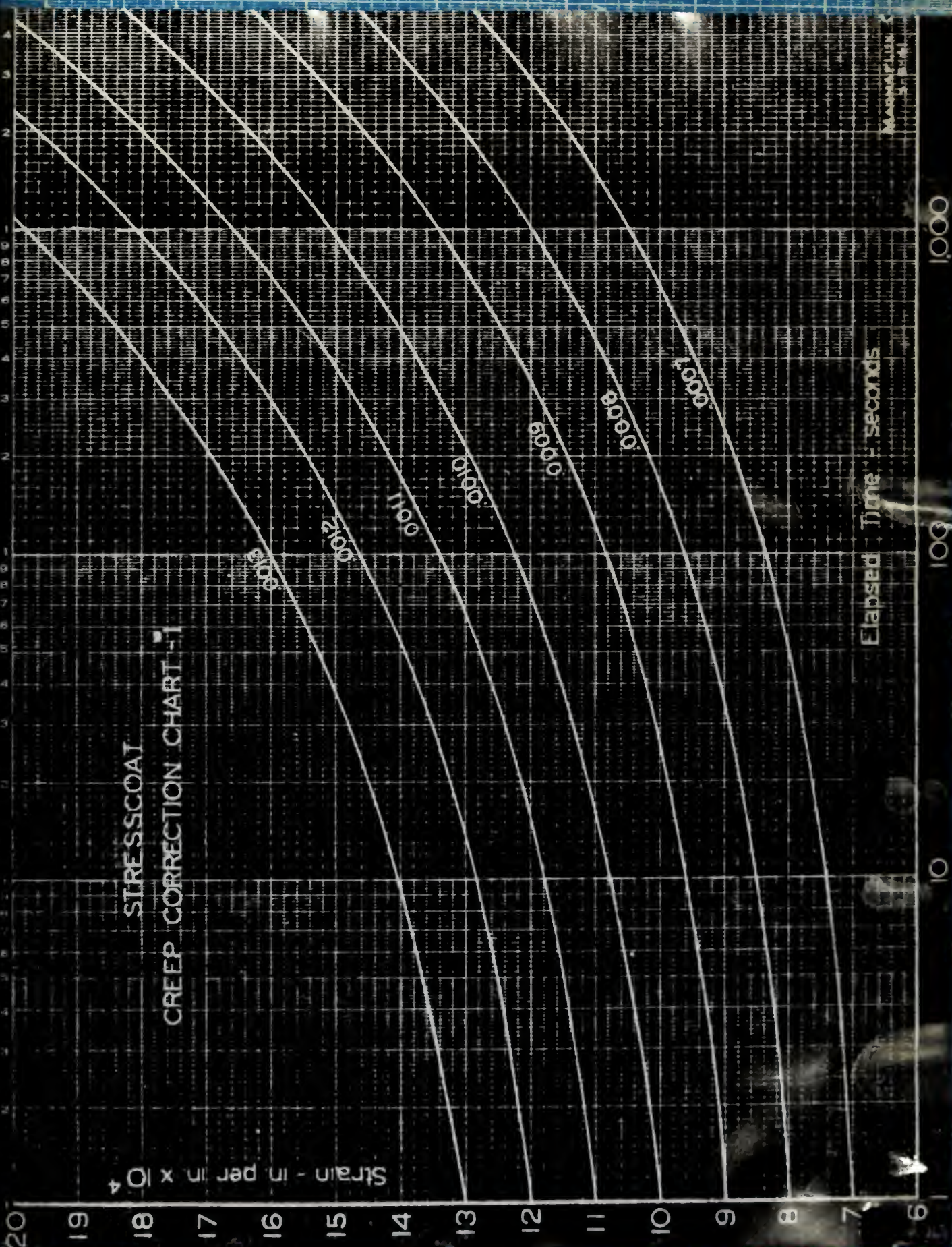
Elapsed Time - seconds

1000

100

10

MADE IN U.S.A.







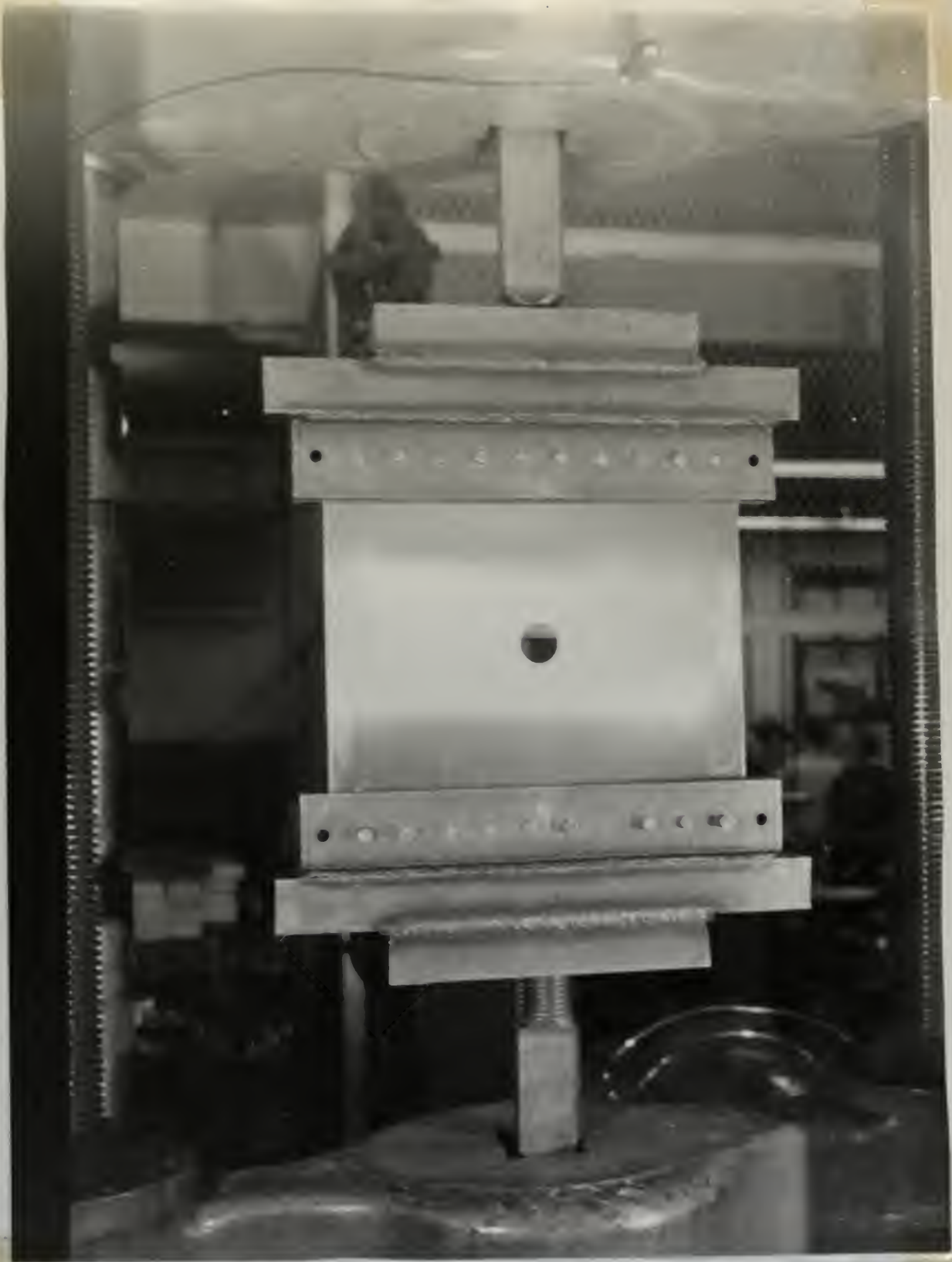


Fig. 4

This is a photograph of the apparatus set for a test run. It shows a front view of the jigs and the large bolt leading to the cross heads of the testing machine. Plate #9 is shown mounted in the jig. The wide light colored band across the center of the plate is the dried coating of lacquer.







Fig. 5

Side view of jig with plate mounted.



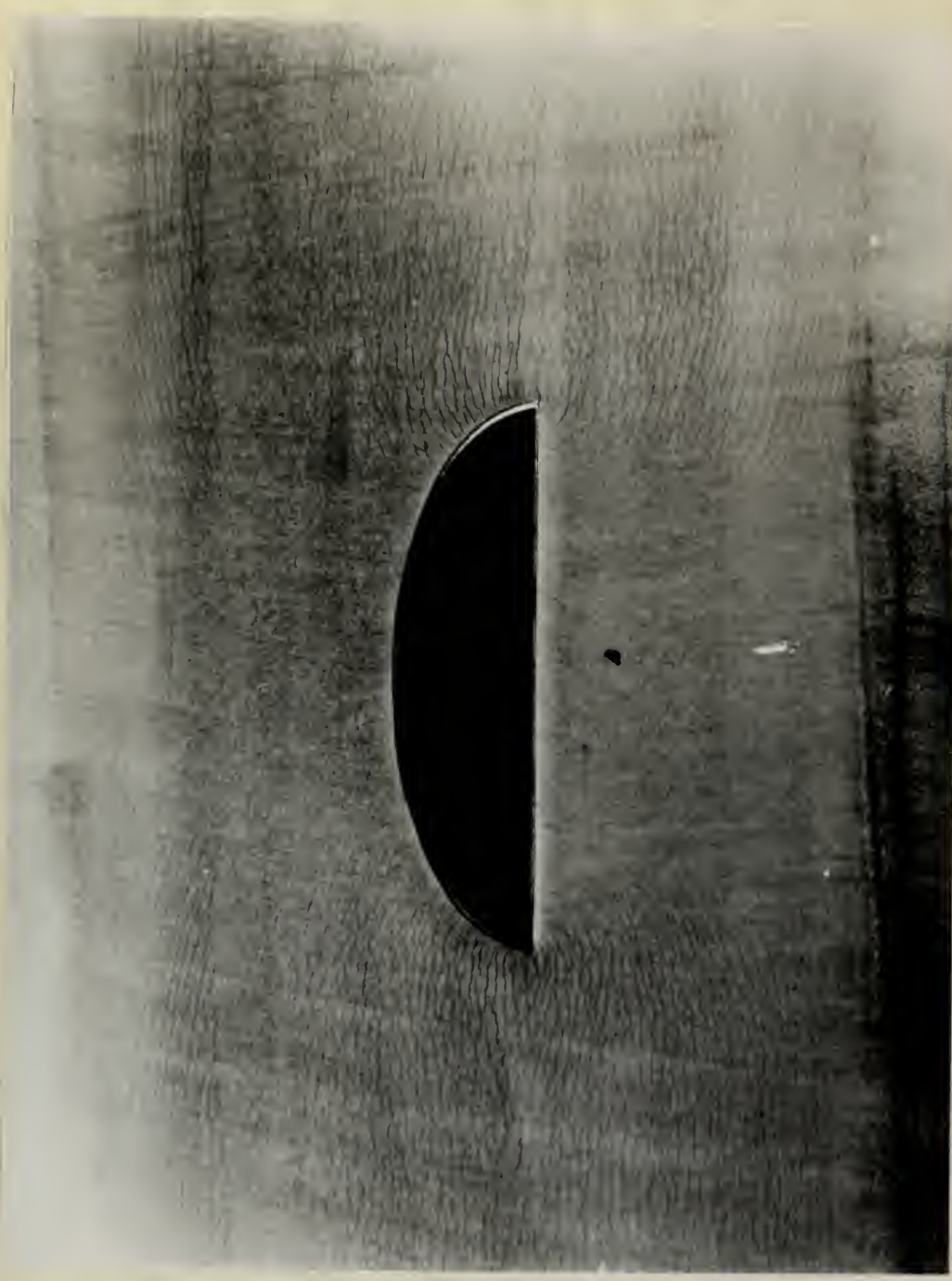


Fig. 6

Close-up view of semi-ellipse of plate #1 after test run showing isotatics. An isotatic is a line of failure of the coating. Cracks first appeared at the corners and as the load was increased the cracks gradually appeared over whole plate.





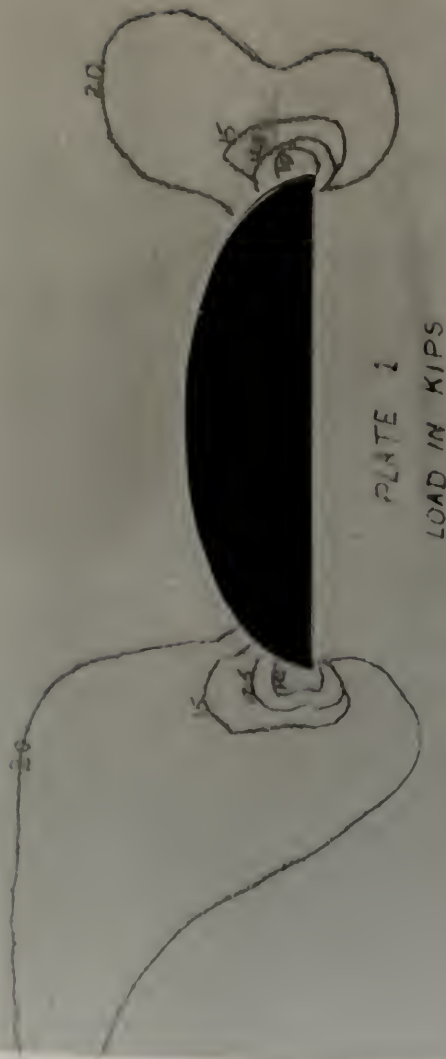


Fig. 7

Plate 1 with isoentatics for loads of 10 kips, 12.5 kips, 15 kips and 20 kips. The isostatics are easily seen in the large 20 kips loop to the left. This loop was probably due to an unequal pull on this particular test run or possibly due to a weak area in the plate in that region.





Fig. 8

Plate 1, showing close up view of isopotentials for loads 1.5 kips to 3.0 kips.







Fig. 9

Plate 2 with isoelectricity for loads 7.5 kips to 30 kips.



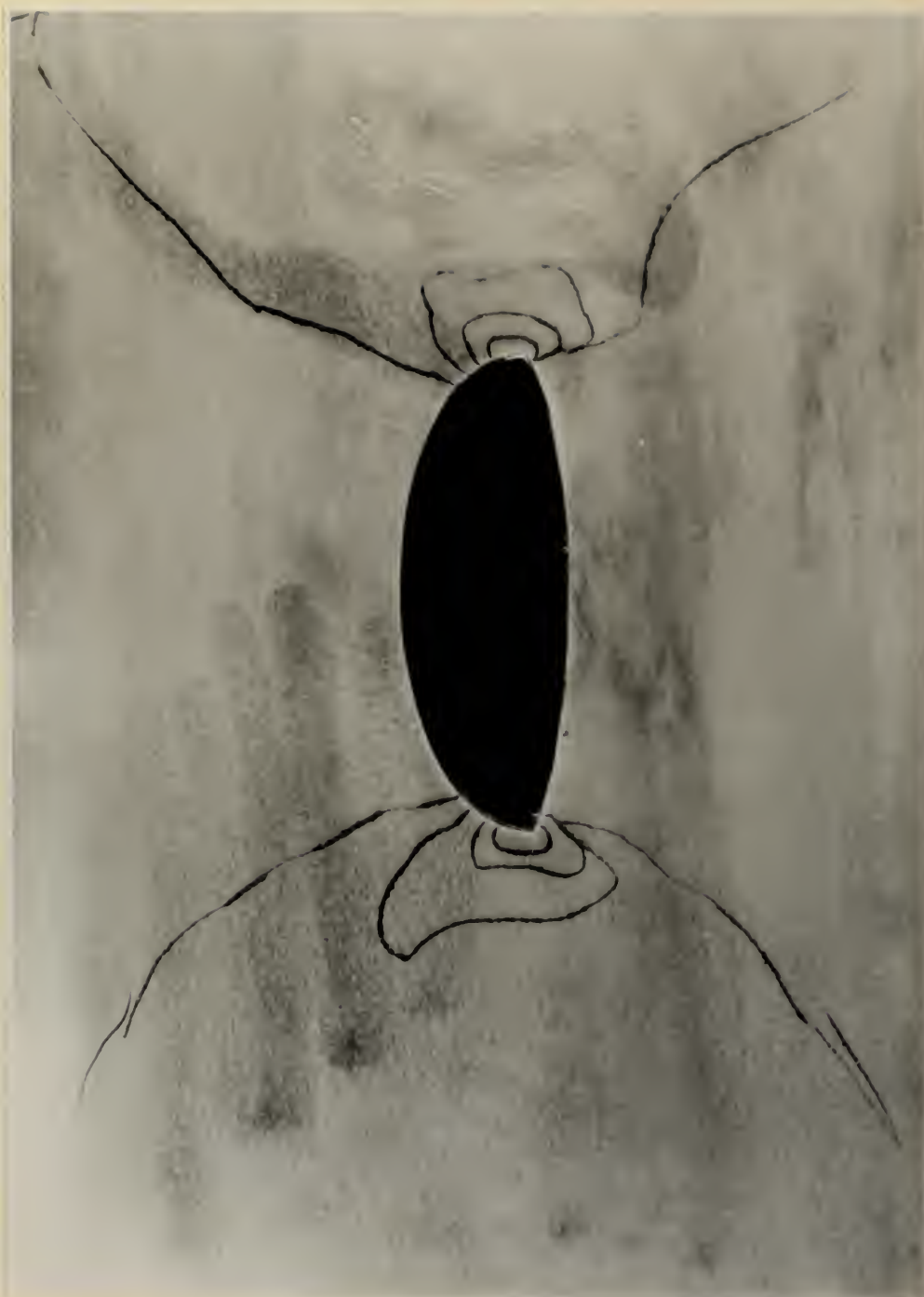


Fig. 10

Close-up view of plate #5 showing isostatistics for loads 5 kips, 7.5 kips, 10 kips and 15 kips. Isostatistics may also be seen in the large loop to the left.





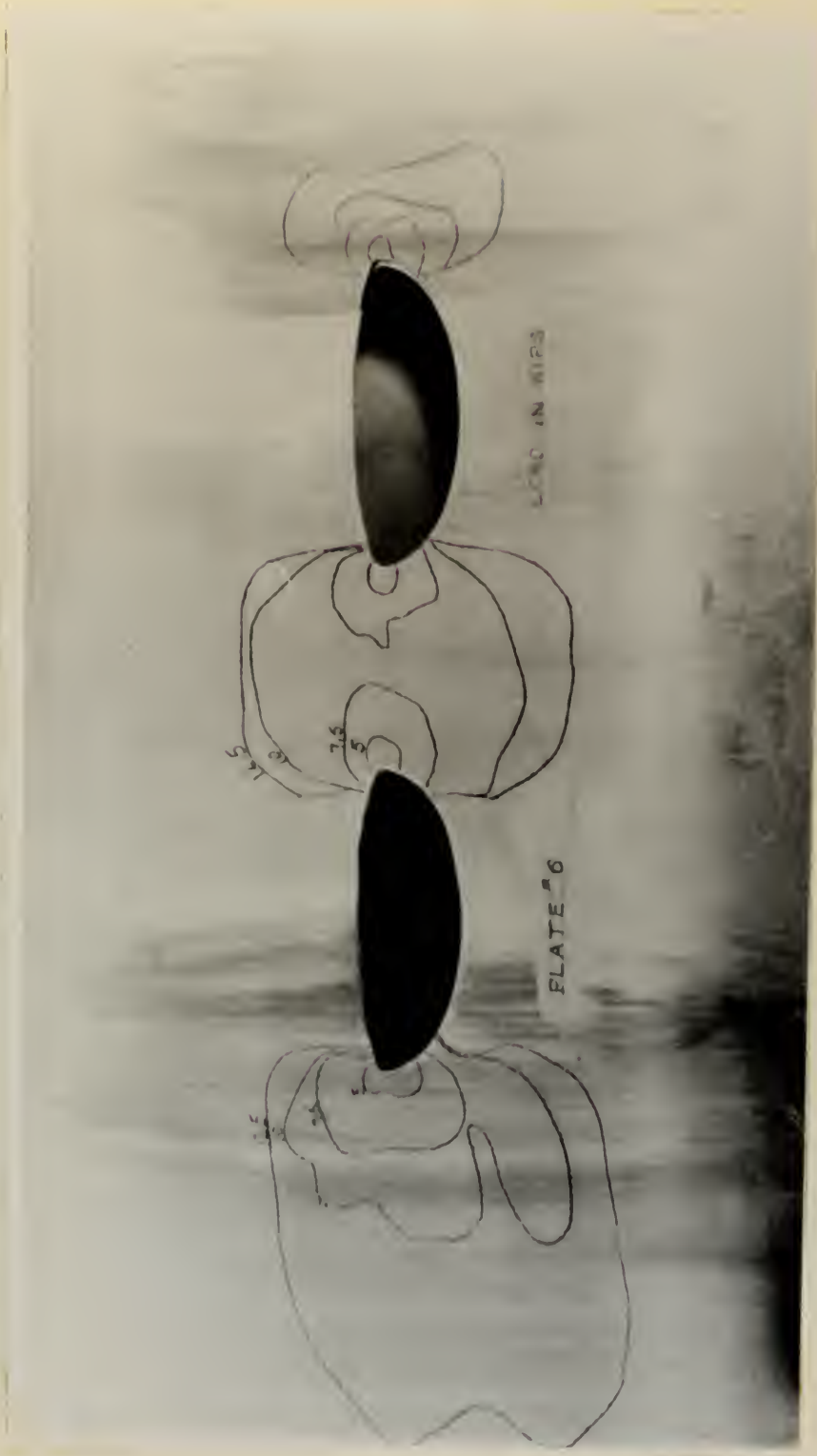


Fig. 11

Wide-view of plate #6 showing isocentatics for loads of 5 kips, 7.5 kips, 10 kips, 12.5 kips.





FIG. 12  
Close-up view of plate #6 showing isothermatics  
for loads of 5 kips to 12.5 kips.








Fig. 13

Plate 7, showing isostatics for loads 7.5 kips to 25 kips. The isostatics may also be seen.





Fig. 14

Close-up view of the three  $1\frac{1}{2}$ " circular openings of plate #10 after it had been tested. The heavy lines are isocentatics for loads of 5 kips, 10 kips, 15 kips, and 20 kips. An isocentatic is a line joining the ends of the cracks formed in the lacquer for a particular load. For instance, a load of 5 kips was applied to the plate and the ends of all cracks were connected by a scratch mark which is the smallest ring near the ends of the horizontal diameter of the circles. The load was increased to 10 kips and the ends of the new cracks were joined by a scratch mark which is the next largest ring, and so on up to 20 kips. The plate was etched with red dye to facilitate photographing.





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Thesis

7476

M35 Marquardt

An investigation of  
stress concentration  
factors around selected  
openings using the  
brittle lacquer technique.

Thesis

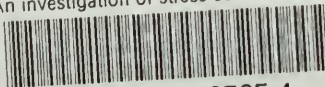
7476

M35 Marquardt

An investigation of  
stress concentration  
factors around selected  
openings using the  
brittle lacquer technique.

thesM35

An investigation of stress concentration



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